Power Generation in Waveguide and Quasi-Optical Technologies Using Hybrid Circuits at Millimetre Waves

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***Abstract* - Terahertz applications require specific components and technologies. To study and develop systems at this frequency range, a preliminary investigation at much lower frequency is often undertaken. This paper presents some results on signal generation using classical hybrid technologies in the X and Ka bands, and some investigations using a quasi-optical technology in the W band are also presented.**

A cavity oscillator at 9.15 GHz with 16 dBm output power and –110 dBc/Hz @ 10kHz phase noise is first described. Power combining is then carried out in a cavity oscillator and also in free space for spatial or "quasi-optical" combining.

The design and measurement of an hybrid varactor frequency multiplier in the millimetre wave range with 12 dB measured conversion losses at 62 GHz and the investigations on a quasi-optical frequency doubler are presented.

I. INTRODUCTION

For sub-millimetre wave applications, like FIRST and SOFIA programs [1], local oscillators at very high frequencies (up to 1 THz) are required for heterodyne receivers. A solution for providing power with low phase noise at sub-millimetre waves associates a low frequency oscillator with one - or more - frequency multipliers. This high frequency oscillator must have sufficient power for efficient driving of the down converter. Waveguide techniques are still widely used for millimetre and sub-millimetre radiometers but planar circuits (hybrid or MMIC) could allow the drawbacks of wave-guide whisker contacted diode multipliers (losses, fragility...) to be overcome. However, no tuning can be done on planar multipliers and accurate modelling of the circuit is required. The Quasi-optical technology could provide a solution to waveguide and planar techniques, but at the same time introduces new challenges.

II. WAVEGUIDE AND PLANAR TECHNOLOGIES FOR POWER GENERATION

A- Cavity oscillator and power combining (in cavity)

Local oscillator characteristics (i.e. output power, phase noise, stability and reliability) are very important for the heterodyne receiver performances. Compared with the vacuum tube technology (klystron,...), solid state components are very attractive in terms of size, weight, reliability and can be mass produced. But for optimum performances and high output power, impedance matching of the active component and power combining are to be achieved.

The oscillator uses a GUNN diode coupled through a circular patch antenna to a cylindrical cavity. A non linear electrical model of the diode was extracted using a load-pull setup ([2]) and electromagnetic simulations of the cavity with the circular patch were carried out to obtain its equivalent impedance at the connection point of the diode. The simulations lead to a cavity TE_{121} resonant mode and the oscillator Harmonic Balance simulation gives a 12.3 dBm output power at 9.17 GHz. Experimental results are shown in fig. 1. Fig. 2 gives the oscillator phase noise measurement.

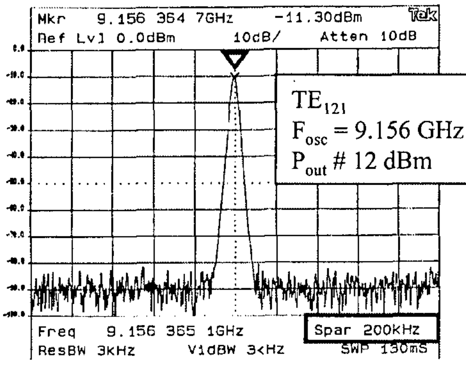

Fig.1: Output spectrum of the cavity oscillator

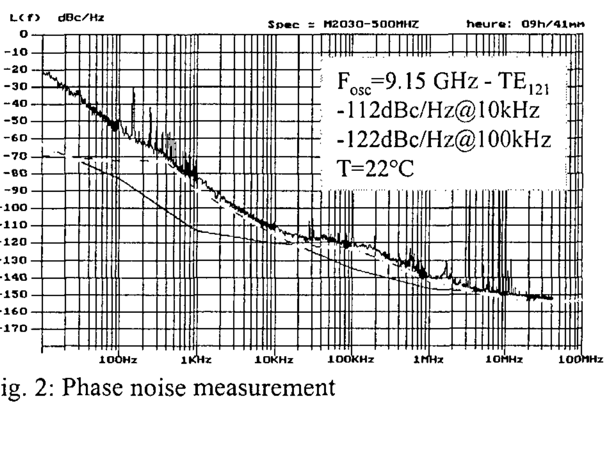

Fig. 2: Phase noise measurement

For power combining, a second diode and its coupling patch antenna was added in the cavity. For optimum oscillation stability and output power, a TE_{113} resonant mode of the cavity was chosen. The oscillation frequency and the ouput power are given in the table I.

Table I: Oscillation frequency and output power of the oscillator with 1 or 2 diodes in the cavity

	TE_{113} Cavity Mode	TE_{121} Cavity Mode
1 GUNN diode	9.98 GHz 16.8 dBm	9.15 GHz 12 dBm
2 GUNN diodes	10.0 GHz 19.4 dBm	No synchronization as expected in simulation

B- Frequency multiplier in planar technology

The source and load impedances and the working conditions of the multiplier are initialized with the Penfield and Rafuse equations [3]. Non-linear simulations are then used to optimize the results and calculate the output power at fundamental and harmonic frequencies.

Realisations at lower frequencies and sensitivity simulations give other informations. First, only radial stubs are used to short-circuit the second harmonic at the input and the fundamental frequency at the output in a very large frequency band. Classical planar technologies such as microstrip or coplanar technologies lead to very low and very high impedance transmission line sections for the diode matching, inducing high losses. So, a technology [4] with microstrip and multilayer coplanar lines was adopted. To obtain very low characteristic impedances, a small substrate thickness is used. But at the same time, high values are required. The multilayer technology (see fig. 3) allows to retain approximately the same central conductor width throughout the circuit, cutting the ground plane under the inductive transmission line sections. Classical coplanar lines are used at the accesses for coaxial probe measurements.

Experimental results (see fig. 4) show that the optimal input frequency is 30.8 GHz for maximum output power (10.8 dBm) and efficiency, but is 28.25 GHz for optimal fundamental rejection (as expected in simulations for output power, efficiency and fundamental rejection).

III. QUASI-OPTICAL TECHNOLOGY FOR POWER GENERATION

The spatial or quasi optical technology is very attractive because it enables a substantial reduction in propagation losses, higher power as well as reliability are obtained by combining the power produced from many solid-state devices and there is no need of a physical connection between the quasi optical components, the source and the load. Some tuning is also possible by moving the parallel quasi optical components (slab, array,...), each in relation to the others.

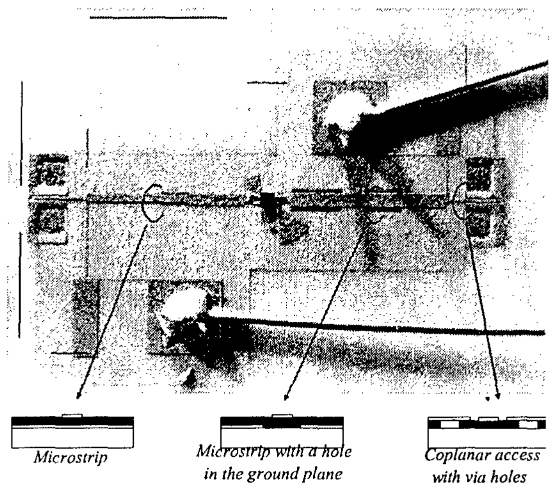

Fig. 3: multilayer technology process

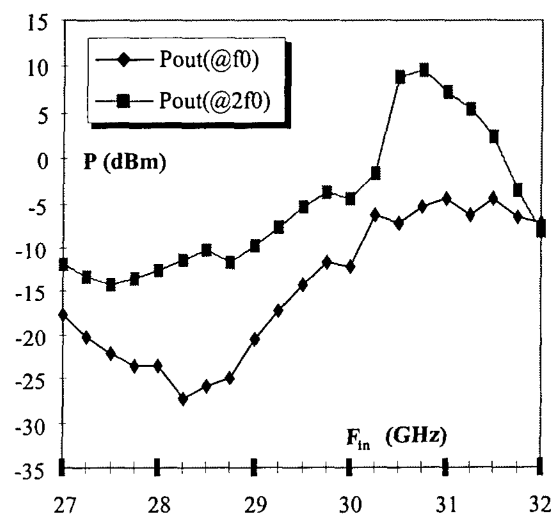

Fig. 4: Output power at fundamental and second harmonic for P_{in}=20 dBm and V=-9 V.

A- Quasi-optical test bench design and its validation

For quasi-optical element characterisation and modelling, two test benches were carried out with Gaussian Optic Lens Antennas (GOLA) in the Ka ([5]) and W band ([6]). These benches were validated for S parameter measurements of passive quasi-optical elements such as polarizer, filter and dielectric slab. The complex permittivity of dielectric slabs is also extracted with high precision ([5]).

Tests were also carried out for simple cascaded quasi-optical functions and well compared with simulations made on classical CAD software (such as HP-MDS) ([5], [6]). So, active quasi-optical functions were then investigated.

B- Oscillators and power combining

For free space combining, a 2 and a 3 diode oscillator combiner using a Whispering Gallery Mode circular dielectric resonator was tested. The structure of the oscillator is shown in fig. 5. The oscillation frequency is 13.51 GHz with 2 diodes as expected from the 13.55 GHz $WGH_{43\delta}$ mode of the resonator and with 3 diodes, the frequency is 13.12 GHz with the 13.25 GHz $WGH_{42\delta}$ mode of the resonator (see fig 6). The output power spectrum is given in fig.7.

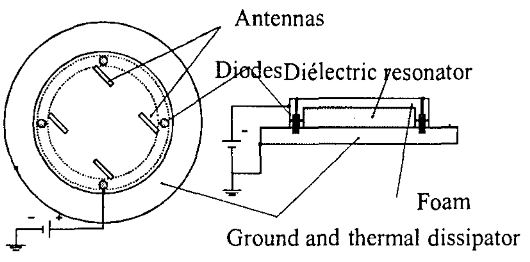

Fig. 5: Quasi-optical structure of the WGM resonator oscillator

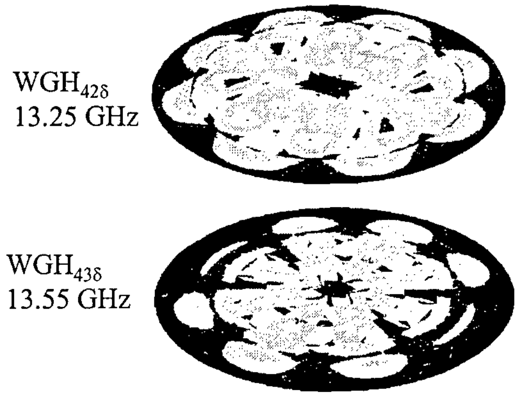

Fig. 6: E field intensity for the WGM resonator

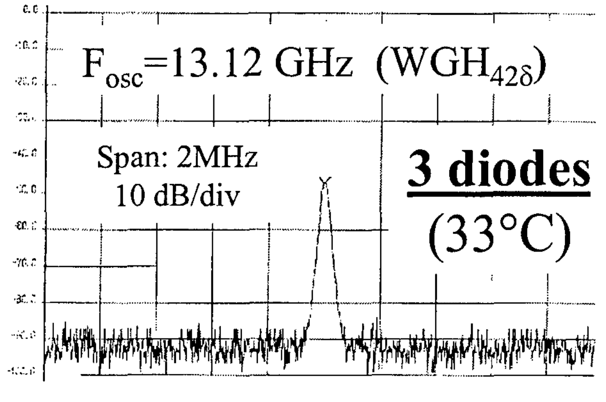

Fig. 7: The WGM resonator oscillator output spectrum measurement.

C- Quasi-optical frequency multiplier

An example of a quasi-optical frequency multiplier is shown in fig.10 with its active grid, polarizers and dielectric slabs. A 38 GHz/76 GHz multiplier was designed and tested with a Ka band GOLA for the 38 GHz input signal, a W band GOLA for the 76 GHz output signal. A Ka band travelling wave tube amplifier (10W) was also used. The active grid is depicted in fig. 8 and fig. 9.

For this first investigation, 9 diodes were mounted on the array but with so few diodes, the performances are not very attractive. The conversion efficiency is less than -40dB at the 76 GHz output frequency. To explain these poor results, it must be pointed out that the 1.7 cm active area diameter with 9 diodes on the grid is too small in comparison with the 8 cm waist diameter of the input Gaussian beam. So, too little power is intercepted by the active area that is, by the 9 dipole antennas connected to the diodes (see fig. 9). Most of the incident power is not transferred to the active device and the efficiency is very low.

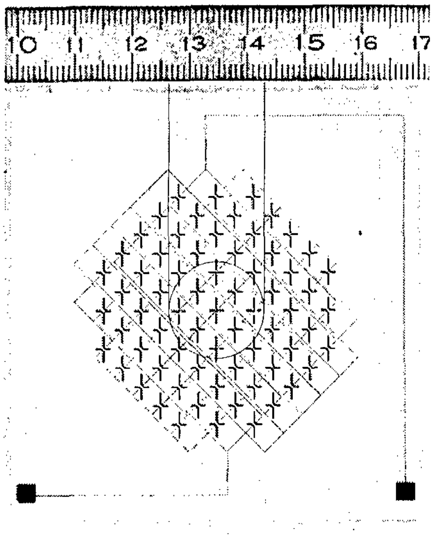

Fig. 8. Photograph of the active grid (dimension in cm).

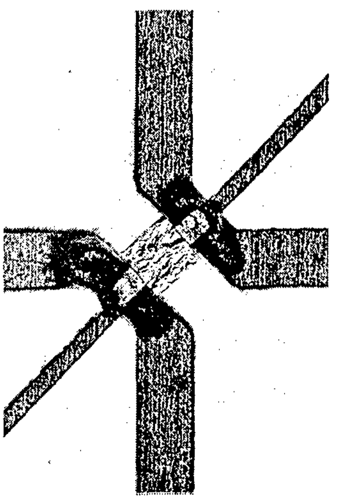

Fig. 9. Detail of the diode connected to dipole antennas.

Non-linear simulations of the whole quasi-optical frequency multiplier were investigated and are still under study. The precise modelling of the component access through the antenna (dipole,...) is very important and rather difficult because it has to take into account all the modes in the structure, the cross-polarisation and the multiple accesses (quasi-optical and active components).

VI. CONCLUSION AND PERSPECTIVES

Power generation at millimeter waves with different techniques and technologies has been presented. Waveguide and planar technology can be used for direct generation with good low noise performance (at lower frequency) or for multiplier with low conversion losses (at high frequency).

Investigations at millimeter waves for spatial or quasi-optical power generation and frequency multplication have been presented too. This technology is very attractive and promising for combining solid state components, tuning circuits and adding power. At the same time, it introduces new challenges for the realization and the global simulation of active non-linear functions.

References

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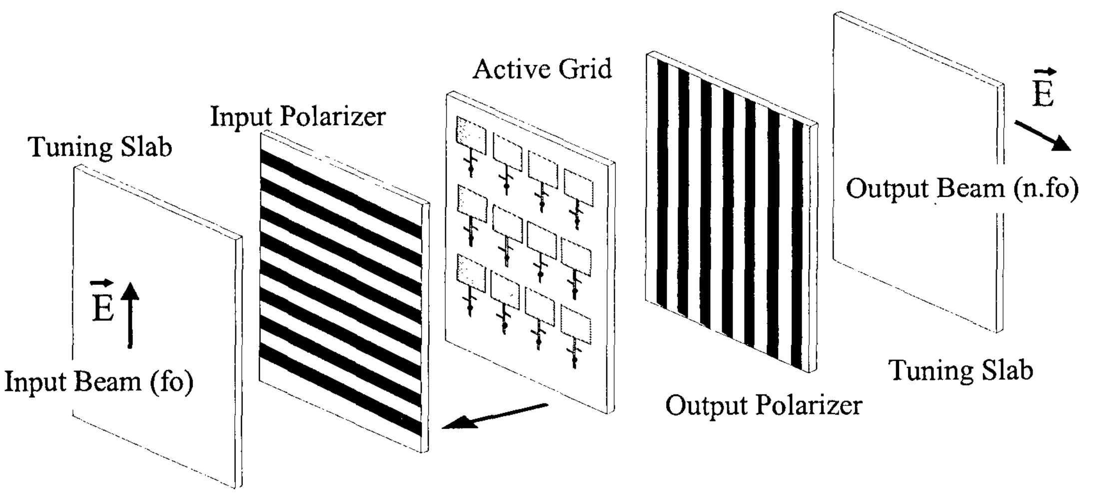

Fig. 10: Quasi-Optical frequency multiplier